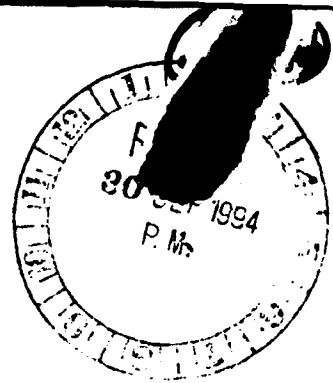


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Perception and Control of Locomotion

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This report describes an empirical study to evaluate the ability to track a constant altitude as a function of the structure in optical flow (manipulated using types of ground texture - splay, depression, dot, and block and the rate of forward motion - global optical flow (GOF) rate). Subjects were asked to track a constant altitude (25 ft) in the face of disturbances to the vertical, lateral, and fore-aft axes. The critical independent variables were texture type and GOF rate. Texture type was manipulated within subjects and GOF rate was manipulated between subjects. Dependent variables included RMS altitude error and correlated control power. The results showed a crossover interaction. For both dependent measures, performance at 0 GOF rate was best with depression angle and poorest with splay angle. The reverse was true at a GOF rate of 3 eyeheights/s. The results are consistent with the hypothesis, suggested by Flach et al. (1992), that the ability to pick-up information about altitude from optic flow depends on the amount of optical flow activity specific to altitude (signal) relative to the flow activity arising from other factors (e.g., motion in the fore-aft and lateral axes) (noise). The optical flow that results from forward motion (GOF rate) is visible in the depression, dot and block textures. This "noise" makes it more difficult to differentiate the optical activity specific to changes in altitude. With splay texture, there is no change in the flow as a result of forward motion. Therefore, performance with splay texture is independent of GOF rate. This hypothesis provides a higher order explanation for previous results on the control of altitude that had been thought to be inconsistent.

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Perception and Control of Locomotion

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Abstract

This report describes an empirical study to evaluate the ability to track a constant altitude as a function of the structure in optical flow (manipulated using types of ground texture - splay, depression, dot, and block and the rate of forward motion - global optical flow (GOF) rate). Subjects were asked to track a constant altitude (25 ft) in the face of disturbances to the vertical, lateral, and fore-aft axes. The critical independent variables were texture type and GOF rate. Texture type was manipulated within subjects and GOF rate was manipulated between subjects. Dependent variables included RMS altitude error and correlated control power. The results showed a crossover interaction. For both dependent measures, performance at 0 GOF rate was best with depression angle and poorest with splay angle. The reverse was true at a GOF rate of 3 eyeheights/s. The results are consistent with the hypothesis, suggested by Flach et al. (1992), that the ability to pick-up information about altitude from optic flow depends on the amount of optical flow activity specific to altitude (signal) relative to the flow activity arising from other factors (e.g., motion in the fore-aft and lateral axes) (noise). The optical flow that results from forward motion (GOF rate) is visible in the depression, dot and block textures. This "noise" makes it more difficult to differentiate the optical activity specific to changes in altitude. With splay texture, there is no change in the flow as a result of forward motion. Therefore, performance with splay texture is independent of GOF rate. This hypothesis provides a higher order explanation for previous results on the control of altitude that had been thought to be inconsistent.

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Perception and Control of Locomotion

According to Haber (1987) jet fighter pilots simply fly into the ground in visual flight conditions with no evidence of mechanical or operational failure or medical emergency at a rate of about two crashes per month. For this reason, it is critical that we understand the information (or lack thereof) that pilots use to control locomotion. Our recent research has focused on the information in optic flow for the control of altitude. Several potential sources of information have been identified. These include splay, optical density, and depression angle (see Flach, Hagen, & Larish, 1992; or Flach & Warren, 1994, for quantitative and graphic descriptions). Recently, there has been some controversy about the relative effectiveness of these various sources of information. Research simulating fixed wing aircraft has consistently found splay to be the most effective source of information for altitude (Flach, Hagen, & Larish, 1992; Warren, 1988; Wolpert, 1988; Wolpert & Owen, 1985; Wolpert, Owen, & Warren, 1983). However, research simulating rotary wing aircraft has consistently found depression angle to be the most effective source of information for altitude (Johnson, Bennett, O'Donnell & Phatak, 1988; Johnson, Tsang, Bennett, & Phatak, 1989). In a recent study in our lab (Kelly, Flach, Garness & Warren 1993), we looked at global optical flow (GOF) rate as a possible intervening variable. The hypothesis was that when a vehicle is in hover or moving at very low forward speeds (low GOF rate), depression angle would be most informative. However, when a vehicle is moving forward at higher speeds (high GOF rate), then splay is most informative. To test this hypothesis, four flow textures (splay only, depression angle only, block, and dot [in principle grid and dot texture should contain both splay and depression information]) were crossed with four global optical flow rates (0, 0.25, 1, 4). Results showed an interaction such that performance with splay only, dot, and block textures was independent of GOF rate and had lower error rates than with depression angle only. Performance was generally poor with depression angle and became worse at the highest flow rate. In no case, not even at the hover (0 GOF rate) condition, was performance with depression angle superior. Thus, we were unable to replicate the results of Johnson et al.

One problem with the Kelly, Flach, Garness, & Warren (1993) study, as well as with previous studies, was that the angular rate of change of texture motion in the field of view was not controlled. The angular rate of change depends on both the motion of the observer and the angular position of the texture element in the field of view. The positioning of texture elements in the Kelly et al. study resulted in greater angular change for the splay texture. In this study, the texture elements were positioned so that the angular rates of texture flow corresponding to a fixed change in altitude were equivalent for each texture type. As with the Kelly et al. study the present study included four texture types (splay, depression angle, block, & dot). Global optical flow (GOF) rate (0 or 3 eyeheights/s) was manipulated between subjects. The hypothesis was that an interaction would be found between texture and global optical flow rate --- with

depression angle resulting in superior control for hover (0 GOF rate) and splay resulting in superior control for the higher GOF rate.

Method

Design. This experiment used a $2 \times 4 \times 3 \times 3$ mixed design. Two levels of global optical flow rate (0 and 3 eyeheights/s) were manipulated between subjects. Texture (4 levels - splay only, depression angle only, grid, & dot) was manipulated within subjects. Also, the magnitude of disturbances to the fore-aft and lateral axes of the vehicle were manipulated within subjects. The magnitudes of these disturbances were .1, 1, or 10 times the power of the disturbance to altitude. Dependent measures included RMS altitude error, RMS control velocity, and the correlation between control and disturbances in the frequency domain.

Subjects. Twenty right-handed males with normal or corrected-to-normal vision were used in this study. Subjects were recruited from the Logicon subject pool at Wright-Patterson AFB. Subjects did not have prior flight experience. Subjects were paid at the rate of \$5.00 per hour.

Apparatus. A 33 MHz 386 computer with an XTAR Graphics board was used to generate the real time graphics displays. These displays were projected onto a 7.6 x 5.7 ft forward projection screen using an Electrohome ECP3000/4000 projection system. Each subject was seated approximately 5.8 ft from the projection screen. Subjects wore occluding goggles that permitted a monocular circular field of view of approximately 40°. A Gravis two-dimensional spring-loaded joystick was used for control input. The software for the real-time interactive graphics used in the experiment was developed by Engineering Solutions, Inc., Columbus, OH.

Procedure. Each subject participated in 36 trials per day for a period of three days. The 36 trials reflect a complete crossing of the four textures, three magnitudes of lateral disturbance, and three magnitudes of fore-aft disturbance. A trial lasted for 120 seconds. The subjects' task was to maintain a constant altitude (25 ft) using the information available in the visual display. Although, the flight path was perturbed on three axes (vertical, lateral, & fore-aft), subjects' control actions affected only the vertical axis. The control dynamics on the vertical axis were first-order. Thus, the rate of change in altitude was proportional to displacement of the stick. At the beginning of each trial there was a 10 s preview period with no disturbances and no control possible. This was followed by a 10 s ramp in period in which control was possible and in which the disturbances were gradually introduced. This was followed by a 100 s tracking period in which performance was measured.

Results

The RMS altitude data from the third block were analyzed using a $2 \times 4 \times 3 \times 3$ mixed design ANOVA. This analysis showed a significant main effect for texture ($F(3,48) = 9.689, p < .001$). Performance was best with splay texture (13.43 ft), block and dot texture were intermediate (15.64 ft & 22.36 ft), and depression angle showed the greatest error (23.97 ft). There was also a significant flow by texture interaction as shown in Figure 1 ($F(3,48) = 13.88, p < .001$). This was a crossover interaction with depression angle resulting in better performance at a GOF rate of 0 and splay angle resulting in better performance at a GOF rate of 3.

The correlated control power measured the correlation between power in the control and power in the three disturbances (altitude, lateral, and fore-aft). A good controller (who responds specifically to altitude) should show a high correlation with the altitude disturbance and low correlations with the lateral and fore-aft disturbances. The results from the third block were analyzed using a $2 \times 4 \times 3 \times 3 \times 3$ mixed design ANOVA. The most important result from this analysis was a significant interaction between flow, texture, and disturbance ($F(6, 96) = 20.41, p < .001$). The correlations between control and the lateral and fore-aft disturbances were very low (approximately 0) and were independent of flow rate and texture type. Figure 2 shows the correlations between control and altitude disturbances as a function of texture and GOF rate. Again we see a crossover interaction. Depression shows the highest correlation for the hover condition, but the lowest correlation for the higher GOF rate condition.

Conclusions

The results support the hypothesis that the value of particular textures as information for the control of altitude depends on the level of GOF rate. In the hover condition, depression angle provides the best information as found by Johnson et al. (1988; 1989). However, for higher rates of GOF, splay angle provides the best information as found by others (Flach, et al., 1992; Warren, 1988; Wolpert et al. 1983, 1985, 1988). An important difference between this study and Kelly, et al. (1993) is that differences in rate of angular change in the optic flow field due to position of the texture elements in the field of view were equated for depression and splay textures. The results are consistent with the hypothesis suggested by Flach et al. (1992) that the ability to pick-up information about altitude from optic flow depends on the amount of optical flow activity specific to altitude (signal) relative to the flow activity arising from other factors (e.g., motion in the fore-aft and lateral axes) (noise). The optical flow that results from forward motion (GOF rate) is visible in the depression, dot and block textures. This "noise" makes it more difficult to differentiate the optical activity specific to changes in altitude. With splay texture, there is no change in the flow as a result of forward motion. Therefore, performance with splay texture is independent of GOF rate. The Flach et al. hypothesis provides an explanation that can account for results that had previously appeared to be inconsistent.

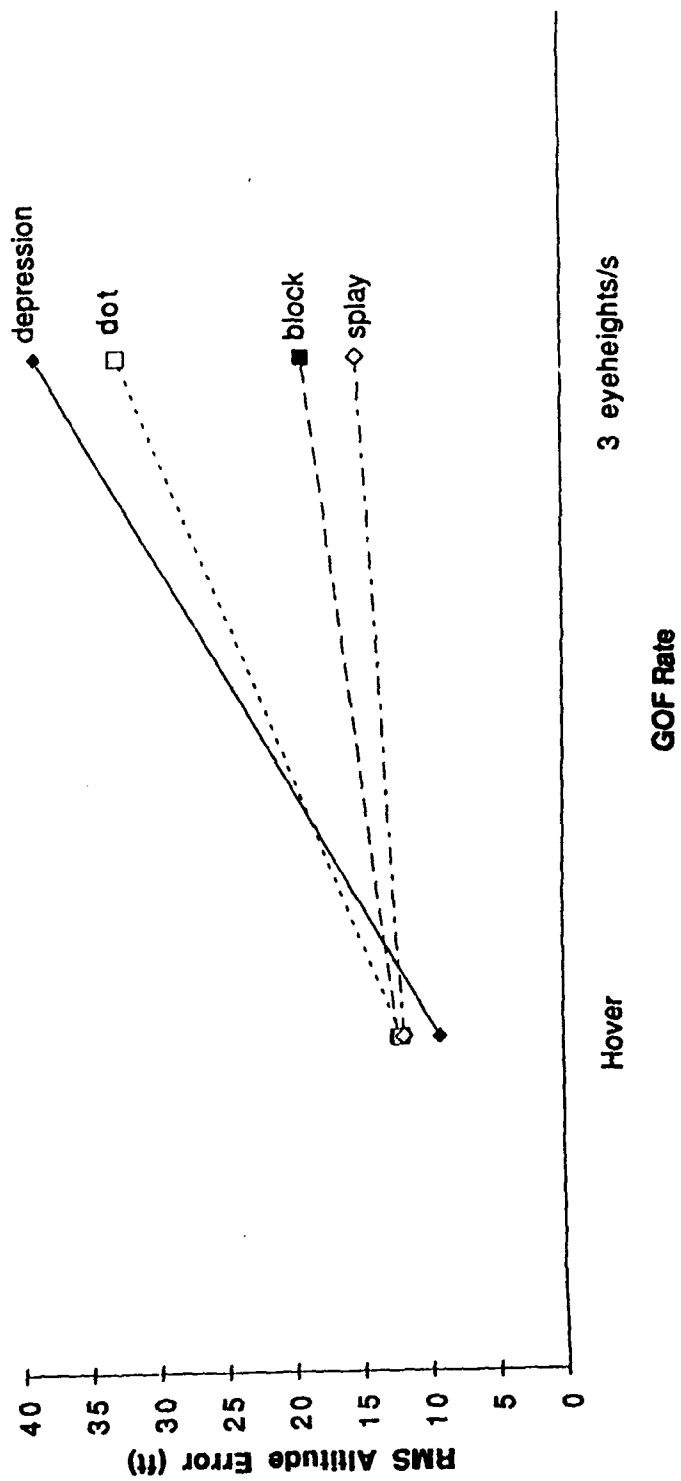


Figure 1. RMS altitude error as a function of global optical flow rate (0 or 3 eyeheights/s) and texture type (splay, depression, dot, and block).

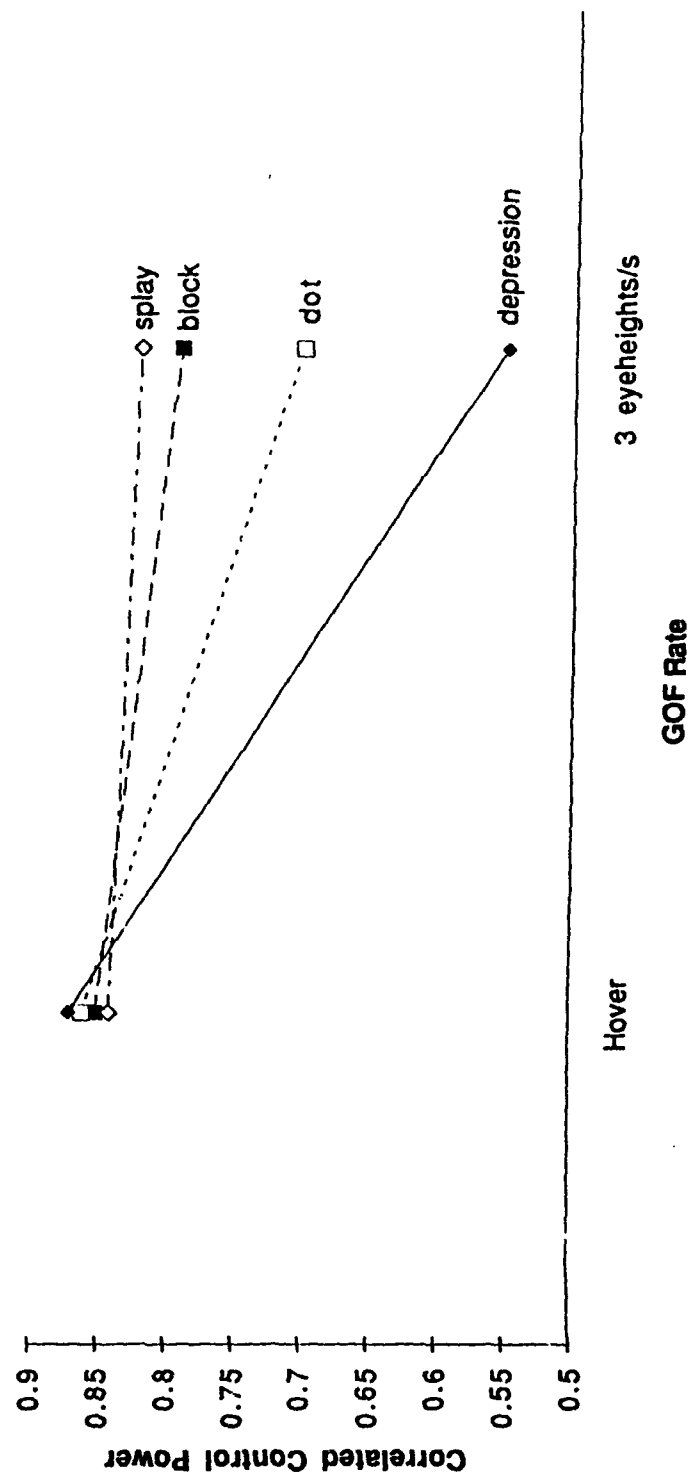


Figure 2. Correlations between control power and altitude disturbance power as a function of global optical flow rate (0 or 3 eyeheights/s) and texture type (splay, depression, dot, and block).

Publication Activity (includes ASSERT + original award)**Journal Articles and Book Chapters:**

- Flach, J.M. (Under review). Situation awareness: Proceed with caution! *Human Factors*
- Flach, J.M. & Bennett, K.B. (In press). Methodological issues for evaluation of interfaces: A case for representative design. In R. Parasuraman & M. Mouloua (Eds.) *Automation and human performance: Theory and application*. Hillsdale, NJ: Erlbaum.
- Flach, J.M. (In press). The ecology of human-machine systems: A personal history. In Flach, J.M., Hancock, P.A., Caird, J. & Vicente, K. (Eds.). *The ecology of human-machine systems I: A global perspective*. Hillsdale, NJ: Erlbaum.
- Flach, J.M. & Warren, R. (In press). Active psychophysics: The relation between mind and what matters. In Flach, J.M., Hancock, P.A., Caird, J. & Vicente, K. (Eds.). *The ecology of human-machine systems I: A global perspective*. Hillsdale, NJ: Erlbaum.
- Flach, J.M. & Warren, R. (In press). Low altitude flight. In Flach, J.M., Hancock, P.A., Caird, J. & Vicente, K. (Eds.). *The ecology of human-machine systems II: Local applications*. Hillsdale, NJ: Erlbaum.
- Flach, J.M., Hancock, P.A., Caird, J. & Vicente, K. (In press). *The ecology of human-machine systems I: A global perspective*. Hillsdale, NJ: Erlbaum.
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Published Conference Proceedings:

- Flach, J.M. (1994). Beyond the servomechanism: Implications of closed-loop, adaptive couplings for modeling human-machine systems. *Proceedings of the '94 Symposium on Human Interaction with Complex Systems*. (p. 401 - 406). Greensboro, NC: Industrial Engineering Department, North Carolina A & T.
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- Hutton, R.J.B., Flach, J.M., Brickman, B.J., Dominguez, C.O., Hettinger, L., Haas, M., & Russel, C. (1994). Keeping in touch: Kinesthetic-tactile information and fly-by-wire. To appear *Proceedings of the 38th Annual Meeting of the Human Factors and Ergonomics Society*. Santa Monica, CA: Human Factors and Ergonomics Society.

Participating Professionals (includes ASSERT + original award)

Graduate Students	RA Support	Proposal Approved	Thesis Completed
Brad Allen	8-90 - 9-91	4-93	Nov 93
Bart Brickman	6-92 -	4-93	Jun 94
Cindy Dominguez			
Sheila Garness	9-92 - 8-94	6-94	Exp. Dec 94
Mark Guisinger			
Jay Holden			
Robert Hutton	6-92 -	3-93	Oct 93
Leigh Kelly	9 -91 - 6-92	7-92	Oct 93
Amy Robison			
Terry Stanard	9 -93 -		

Theses

Kelly, L. (1993). *Altitude control and the interaction of global optical flow with ground texture type*. Psychology Department, Wright State University.

Hutton, R. (1993). *The role of activity in the perception of three dimensional objects from dynamic occlusion*. Psychology Department, Wright State University.

Allen, Bradely, L. (1993) *Dynamic occlusion as information for object recognition: Effects of observer mode uncertainty*. Psychology Department, Wright State University.

Brickman, Bart, J. (1994). *The effects of noise and temporally delayed sensory feedback on perception/action coupling*. Psychology Department, Wright State University.

Undergraduate Students: Jeffrey Light Honors thesis completed in Spring 1994.

Interactions

Other Support from Air Force Labs.

Presentations:

Dominguez, C., Hutton, R., & Flach, J.M. (1994). Human performance issues in video surgery. 1994 ERGO EXPO Symposium. Dayton, OH. (Sept 20)

Flach, J.M. (1994). Error in adaptive systems: Reconsidering fundamental assumptions about causality. Invited paper presented at the workshop on *Approaches to Modeling the Evolution and Breakdown of Adaptive Systems*. Annual Workshop on New Technologies and Work -- NeTWORK. Bad Homburg, Germany. (June 16-18)

- Flach, J.M. (1994). Going with the flow: Taoism, low altitude flight, and the meaning of life. Invited presentation at the Beckman Center, University of Illinois, Urbana, IL. (April 22)
- Flach, J.M. (1994). Fitts' Law: Might the force be with it. Invited presentation to the Kinesiology Department, University of Illinois, Urbana, IL. (April 22).

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